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Energy Resource Allocation in Iran: A Fuzzy Multi-Objective Analysis

Aliyeh Kazemi[a*], M. Reza Mehregan[a], Hamed Shakouri G.[b], Mahnaz Hosseinzadeh[a]

[a] *Department of Industrial Management, Faculty of Management, University of Tehran, Tehran, Iran*
[b] *Department of Industrial Engineering, Faculty of Engineering, University of Tehran, Tehran, Iran*

Abstract

Energy plays a key role in the development of nations and provides vital services and means that improve quality of life. Formulation of an energy model will help in the proper allocation of available energy resources. The objective of this paper is to allocate optimally to each end-use a certain amount of energy to be supplied by a given resource in Iran. In this research, the energy allocation process is looked at from three points of view: policy, economy and environment. In this way, energy demands of end-uses are forecasted using neural networks and fuzzy linear regression methods. The outcomes are used in a fuzzy multi-objective linear programming model, which determines the optimum allocation of energy resources of Iran from 2011 to 2020. The results provide scientific basis for the optimal allocation of energy resources in meeting the future energy demand in Iran.

Keywords: energy resources allocation; forecasting; multi-objective linear programming; fuzzy model; subsidies lifting; greenhouse gas

1. Introduction

Energy is a vital input for social and economic development of any nation. Planning for proper allocation of energy resources to different end-uses is crucial. Energy resources in Iran consist of the third largest oil reserves and the second largest natural gas reserves in the world. On the other hand the energy consumption in the country is extraordinarily higher than international standards. Certainly planning for the optimal allocation of the enormous resources of oil and gas is essential. In this approach energy

* Corresponding author

E-mail address: aliyehkazemi@ut.ac.ir

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models are valuable mathematical tools which applied to aid decision-making in energy planning, to analyze energy policies.

During the past decades a variety of energy resources allocation models have been developed [1-4]. In 1998, Mezher et al. have formulated a multi-objective goal programming model to allocate specific energy resources to the various household end-uses in Lebanon [1]. Agrawal and Singh have analyzed a fuzzy multi-objective energy allocation problem for cooking use in UP households [2]. Borges and Antunes have developed a fuzzy multiple objective decision support model to study the relationships between the economy and the energy sector on a national level [3]. A fuzzy linear model has been formulated by Sadeghi and Hosseini in 2006 for optimization of supply energy system of Iran [4].

In this paper, the multi-objective energy resource allocation problem is studied in a fuzzy manner, with the objectives which include political, economic and environmental concerns. The remaining parts of the paper are organized as follows: In section 2, after presenting the reference energy system of Iran, the energy supply model is introduced. Details of the proposed model and numerical results are described in section 3. A brief review of the paper is given in section 4.

2. Energy supply model of Iran

2.1. Reference energy system of the model

Figure 1 shows reference energy system that is a simplified reference energy system of Iran.

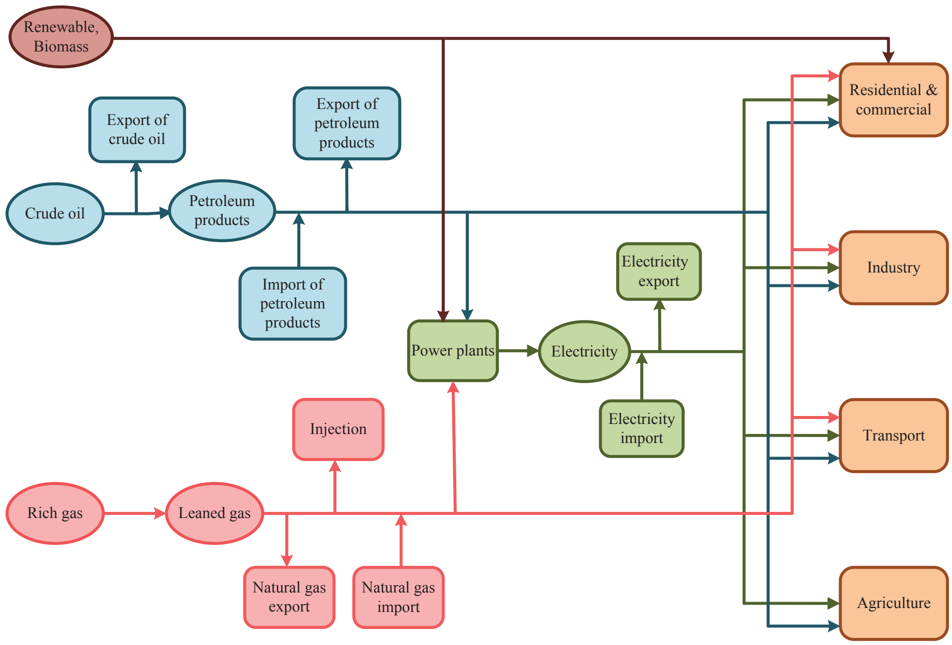

Fig. 1. Reference energy system of Iran

The reference energy system is represented by an oriented network in which the energy, starting in the form of primary energy is flowing and is gradually transformed further down to useful energy so as to satisfy a given exogenous demand. The reference energy system consists of four subsectors, they are oil, gas, electricity and others (renewable and biomass) subsectors. The end uses are residential and commercial, transport, industry and agriculture sectors. In the oil subsector, crude oil can be exported or sent to refineries. The refineries provide the bulk of domestic demand for petroleum products and the surplus of their supply is exported. In the gas subsector, Rich gas is refined. Refined natural gas-called leaned gas- is either sent out via pipeline grids to consumer terminals or is injected to oil fields for secondary or tertiary recovery of oil fields. The surplus of their supply is exported. In the electricity subsector, power plants produce the secondary energy which is electricity. Various sectors of the country such as residential and commercial, industry and agriculture are major final consumers of electricity. Network connections between neighbour countries provide substantial means for cooperation among countries for electricity import as well as export. In the other subsector renewable and biomass are considered. Iran's renewable energy and biomass consumption is negligible. The main subsectors are oil, gas and electricity subsectors.

2.2. Structure of the model

2.2.1. The objective functions

Three objective functions are considered in this work. What follows is a description of these objectives, together with the corresponding mathematical formulation.

- *Minimization of energy imports*

Energy imports to be minimized, taking into account the energy dependence of the country. Thus, the first objective function followes:

$$Min\ \ z_1(T) = I_o(T) + I_b(T) + I_g(T) + I_e(T) \tag{1}$$

where

$I_o(T)$ decision variable representing petroleum products imports except gasoline in time T (MBOE)

$I_b(T)$ decision variable representing gasoline imports in time T (MBOE)

$I_g(T)$ decision variable representing natural gas imports in time T (MBOE)

$I_e(T)$ decision variable representing electricity imports in time T (MBOE)

- *Maximization of economic benefits*

This objective function considers economic benefits regarding price of various energy carriers, imports and exports and the subsidies are given by government on the different energy carriers. Therefore, the second objective function is represented as:

$$\begin{aligned} Max\ \ z_2(T) = {} & P_c(T) \times \mathrm{E_c}(T) + P_o(T)(E_o(T) - I_o(T) - h_o(T)(x_{or}(T) + x_{ot}(T) + x_{oi}(T) + x_{oa}(T) \\ & + x_{op}(T)) + P_b(T)(E_b(T) - I_b(T) - h_o(T)(x_{bt}(T)) + P_g(T)(E_g(T) - I_g(T) - h_g(T)(x_{gr}(T) + \\ & x_{gt}(T) + x_{gi}(T) + x_{gp}(T)) + P_e(T)(E_e(T) - I_e(T) - h_e(T)(x_{er}(T) + x_{et}(T) + x_{ei}(T) + x_{ea}(T)) \end{aligned} \tag{2}$$

where

$P_c(T)$ crude oil price in time T (\$/MBO)

$E_c(T)$ decision variable representing crude oil exports in time T (MBO)

$P_o(T)$ petroleum products (except gasoline) price in time T (\$/MBOE)

$E_o(T)$ decision variable representing petroleum products exports in time T (MBOE)

$h_o(T)$ subsidies given by government on petroleum products in time T (percent of total)

$x_{or}(T)$ decision variable representing petroleum products allocated to the residential and commercial sector in time T (MBOE)

$x_{ot}(T)$ decision variable representing petroleum products allocated to the transport sector in time T (MBOE)

$x_{oi}(T)$ decision variable representing petroleum products allocated to the industry sector in time T (MBOE)

$x_{oa}(T)$ decision variable representing petroleum products allocated to the agriculture sector in time T (MBOE)

$x_{op}(T)$ decision variable representing petroleum products allocated to the power plants in time T (MBOE)

$P_b(T)$ gasoline price in time T (\$/MBOE)

$E_b(T)$ decision variable representing gasoline exports in time T (MBOE)

$x_{bt}(T)$ decision variable representing gasoline allocated to the transport sector in time T (MBOE)

$P_g(T)$ natural gas price in time T (\$/MBOE)

$E_g(T)$ decision variable representing natural gas exports in time T (MBOE)

$h_g(T)$ subsidies given by government on natural gas in time T (percent of total)

$x_{gr}(T)$ decision variable representing natural gas allocated to the residential and commercial sector in time T (MBOE)

$x_{gt}(T)$ decision variable representing natural gas allocated to the transport sector in time T (MBOE)

$x_{gi}(T)$ decision variable representing natural gas allocated to the industry sector in time T (MBOE)

$x_{gp}(T)$ decision variable representing natural gas allocated to the power plants in time T (MBOE)

$P_e(T)$ electricity price in time T (\$/MBOE)

$E_e(T)$ decision variable representing electricity exports in time T (MBOE)

$h_e(T)$ subsidies given by government on electricity in time T (percent of total)

$x_{er}(T)$ decision variable representing electricity allocated to the residential and commercial sectors in time T (MBOE)

$x_{et}(T)$ decision variable representing electricity allocated to the transport sector in time T (MBOE)

$x_{ei}(T)$ decision variable representing electricity allocated to the industry sector in time T (MBOE)

$x_{ea}(T)$ decision variable representing electricity allocated to the agriculture sector in time T (MBOE)

- *Minimization of greenhouse gas emissions*

Environmental emissions are a threat to health as well as sustainability of the development process. Thus, the third objective is to minimize greenhouse gas emissions. Three major pollutants are considered to describe the impact of human activities on the air quality. These are carbon dioxide (CO2), methane (CH4) and nitrous oxide (N2O). The emissions due to the combustion of any energy resources depend on its composition. In this paper, three types of fuels are adopted: petroleum products, natural gas and traditional fuels. The third objective function is represented as:

$$\begin{aligned} Min\ \ z_3(T) = m_{or}x_{or}(T) + m_{gr}x_{gr}(T) + m_{sr}x_{sr}(T) + m_{oi}x_{oi}(T) + m_{gi}x_{gi}(T) + m_{ot}x_{ot}(T) + \\ m_{gt}x_{gt}(T) + m_{oa}x_{oa}(T) + m_{op}x_{op}(T) + m_{gp}x_{gp}(T) \end{aligned} \quad (3)$$

where

m_{or} greenhouse gas emissions consuming petroleum products in the residential and commercial sectors (million tonnes of Carbon Dioxide Equivalent (MTCO2e)/MBOE)

m_{gr} greenhouse gas emissions consuming natural gas in the residential and commercial sectors (MTCO2e/MBOE)

m_{sr} greenhouse gas emissions consuming traditional fuels in the residential and commercial sectors (MTCO2e/MBOE)

$x_{sr}(T)$ decision variable representing traditional fuels allocated to the residential and commercial sector in time T (MBOE)

m_{oi} greenhouse gas emissions consuming petroleum products in the industry sector (MTCO2e/MBOE)

m_{gi} greenhouse gas emissions consuming natural gas in the industry sector (MTCO2e/MBOE)

m_{ot} greenhouse gas emissions consuming petroleum products in the transport sector (MTCO2e/MBOE)

m_{gt} greenhouse gas emissions consuming natural gas in the transport sector (MTCO2e/MBOE)

m_{oa} greenhouse gas emissions consuming petroleum products in the agriculture sector (MTCO2e/MBOE)

m_{op} greenhouse gas emissions consuming petroleum products in the power plants (MTCO2e/MBOE)

m_{gp} greenhouse gas emissions consuming natural gas in the power plants (MTCO2e/MBOE)

2.2.2. Model constraints

The constraints of the model consist of:

- flow balance equations at network:

$$
\begin{aligned}
&\tilde{c}(T) = E_c(T) + x_{co}(T)\\
&o(T) = x_{co}(T) \times f_o(T)\\
&o(T) + I_o(T) + I_b(T) = E_o(T) + x_{or}(T) + x_{oi}(T) + x_{ot}(T) + x_{oa}(T) + x_{op}(T)\\
&x_{ot}(T) \times p_{bt}(T) = o(T) \times z_b(T) + I_b(T) - E_b(T)\\
&x_{bt}(T) = o(T) \times z_b(T)\\
&\tilde{g}(T) = R(T) \times f_g(T)\\
&g(T) + I_g(T) = E_g(T) + x_{gn}(T) + x_{gr}(T) + x_{gi}(T) + x_{gt}(T) + x_{gp}(T)\\
&sp(T) + (x_{op}(T) + x_{gp}(T)) \times f_p(T) = e_1(T)\\
&sp(T) = e_1(T) \times p_{sp}(T)\\
&e(T) = e_1(T) \times w(T)\\
&e(T) + I_e(T) = E_e(T) + x_{er}(T) + x_{ei}(T) + x_{et}(T) + x_{ea}(T)
\end{aligned}
\tag{4}
$$

where

$\tilde{c}(T)$ crude oil exploitation in time T (MBO). $c(T)$ can spread 2% to right and 4% to left at the most. Thus $c(T)$ can be defined as a fuzzy number $\tilde{c}(T)$ that $\tilde{c}(T) = (c(T), 4\%c(T), 2\%c(T))$.

$x_{co}(T)$ decision variable representing crude oil converts to petroleum products in time T (MBO)

$o(T)$ petroleum products production in time T (MBOE)

$f_o(T)$ oil refineries efficiency in time T

$p_{bt}(T)$ estimated gasoline consumption in transport sector in time T (percent of total)

$z_b(T)$ estimated gasoline production in refineries in time T (percent of total)

$\tilde{g}(T)$ leaned gas production in time T (MBOE). $g(T)$ can spread 3% to right and 11% to left at the most. Thus $g(T)$ can be defined as a fuzzy number $\tilde{g}(T)$ that $\tilde{g}(T) = (g(T), 11\%g(T), 3\%g(T))$.

$R(T)$ rich gas exploitation in time T (MBOE)

$f_g(T)$ gas refineries efficiency in time T

$x_{gn}(T)$ decision variable representing natural gas injection into the oil reservoirs in time T (MBOE)

$sp(T)$ electricity produced by renewable energy resources in time T

$f_p(T)$ power plants efficiency in time T

$e_1(T)$ electricity production in time T (MBOE)

$p_{sp}(T)$ estimated electricity production from renewable energy resources in time T (percent of total)

$e(T)$ electricity after eliminating the estimated transmission and distribution losses in time T (MBOE)

$w(T)$ estimated electricity transmission and distribution losses in time T (percent of total)

- energy demands: The demand constraints are generated for each sector to ensure that the energy outputs from the demand technologies are greater than or equal to the end-use demands. The actual demand for total energy, petroleum products, natural gas and electricity for each sector is predicted using the neural networks and linear regression models based on socio-economic indicators.

$$
\begin{aligned}
&x_{sr}(T)+x_{or}(T)+x_{gr}(T)+x_{er}(T)\geq \widetilde{D}_r(T)\\
&x_{or}(T)\geq \widetilde{D}_{or}(T)\\
&x_{gr}(T)\geq \widetilde{D}_{gr}(T)\\
&x_{er}(T)\geq \widetilde{D}_{er}(T)\\
&x_{oi}(T)+x_{gi}(T)+x_{er}(T)\geq \widetilde{D}_i(T)\\
&x_{oi}(T)\geq \widetilde{D}_{oi}(T)\\
&x_{gi}(T)\geq \widetilde{D}_{gi}(T)\\
&x_{ei}(T)\geq \widetilde{D}_{ei}(T)\\
&x_{ot}(T)+x_{gt}(T)+x_{et}(T)\geq \widetilde{D}_t(T)\\
&x_{ot}(T)\geq \widetilde{D}_{ot}(T)\\
&x_{oa}(T)+x_{ea}(T)\geq \widetilde{D}_a(T)\\
&x_{oa}(T)\geq \widetilde{D}_{oa}(T)\\
&x_{ea}(T)\geq \widetilde{D}_{ea}(T)\\
&x_{op}(T)+x_{gp}(T)\geq \widetilde{D}_p(T)\\
&x_{gp}(T)\geq \widetilde{D}_{gp}(T)\\
&x_{gn}(T)\geq \widetilde{D}_{gn}(T)
\end{aligned}
\tag{5}
$$

where

$\widetilde{D}_r(T)$ residential and commercial energy demand in time T (MBOE)

$\widetilde{D}_{or}(T)$ residential and commercial petroleum products demand in time T (MBOE)

$\widetilde{D}_{gr}(T)$ residential and commercial natural gas demand in time T (MBOE)

$\widetilde{D}_{er}(T)$ residential and commercial electricity demand in time T (MBOE)

$\widetilde{D}_i(T)$ industry energy demand in time T (MBOE)

$\widetilde{D}_{oi}(T)$ industry petroleum products demand in time T (MBOE)

$\widetilde{D}_{gi}(T)$ industry natural gas demand in time T (MBOE)

$\widetilde{D}_{ei}(T)$ industry electricity demand in time T (MBOE)

$\widetilde{D}_t(T)$ transport energy demand in time T (MBOE)

$\tilde{D}_{ot}(T)$ transport petroleum products demand in time T (MBOE)

$\tilde{D}_{gt}(T)$ transport natural gas demand in time T (MBOE)

$\tilde{D}_{et}(T)$ transport electricity demand in time T (MBOE)

$\tilde{D}_{a}(T)$ agriculture energy demand in time T (MBOE)

$\tilde{D}_{oa}(T)$ agriculture petroleum products demand in time T (MBOE)

$\tilde{D}_{ea}(T)$ power plants electricity demand in time T (MBOE)

$\tilde{D}_{p}(T)$ power plants energy demand in time T (MBOE)

$\tilde{D}_{gp}(T)$ power plants natural gas demand in time T (MBOE)

$\tilde{D}_{gn}(T)$ natural gas demand for injection into the oil reservoirs in time T (MBOE). $D_{gn}(T)$ can spread 1% to right and 30% to left at the most. Thus $D_{gn}(T)$ can be defined as a fuzzy number $\tilde{D}_{gn}(T)$ that $\tilde{D}_{gn}(T) = (D_{gn}(T), 30\% D_{gn}(T), 1\% D_{gn}(T))$.

- upper and lower bounds: upper and lower bounds are imposed on the production capacity of natural gas and electricity in the transport sector. Upper bound is imposed on traditional fuels in the residential and commercial sectors and lower bounds are imposed on crude oil and natural gas exports.

$$\begin{aligned} & x_{gt}(T-1) \le x_{gt}(T) \le U_{gt}(T) \\ & x_{et}(T-1) \le x_{et}(T) \le U_{et}(T) \\ & x_{sr}(T) \le U_{sr}(T) \\ & E_c(T-1) \le E_c(T) \\ & E_g(T-1) \le E_g(T) \end{aligned} \tag{6}$$

where

$U_{gt}(T)$ upper bound of natural gas consumption in the transport sector in time T (MBOE)

$U_{et}(T)$ upper bound of electricity consumption in the transport sector in time T (MBOE)

$U_{sr}(T)$ upper bound of traditional fuels consumption in the residential and commercial sectors in time T (MBOE)

3. Model output

Data related to the model were collected from a vast number of different sources such as Petroleum Ministry of Iran, Ministry of Energy of Iran [5], National Iranian Oil Company (NIOC), Institute for International Energy Studies (IIES) [6], Iranian Fuel Conservation Company (IFCO) [7], National Iranian Oil Refining & Distribution Company (NIORDC), Central Bank of Iran [8] and Statistical Centre of Iran [9]. The model is solved using the LINGO software. Figure 2 represents the middle bound values of crude oil, petroleum products and natural gas optimal allocations. As can be seen from the figures, a large portion of crude oil will be allocated for export. The crude oil exports sholud be declined scince 2016 due to the fact that oil reservoirs are getting old. Petroleum products export will be declined, respectively. A large portion of natural gas should be allocated for export. Transport sector will be the major consuming sector of petroleum products. It sould be mentioned that allocation of a small amount of natural gas to the sector is due to the lack of infrastructure. A small amount of petroleum products should be allocated to residential and commercial sectors and this comes mainly from the fact that expantion of gas networks in the country has resulted in a significant decrease in petroleum products consumption in these sectors. On the other hand a large amount of natural gas will be allocated to meet the increasing end-uses demands in the sectors. Petroleum products and natural gas allocation will grow in industry sector in response to the increasing energy demands in the sector. A small portion of petroleum products should be allocated to agriculture sector to meet the small demand of the sector. Natural gas will be allocated with higher amounts to powerplants due to its lower greenhouse gas emissions instead of petroleum products. Moreover, a considerable portion of natural gas should be injected into the oil reservoirs to inhance the oil recovery.

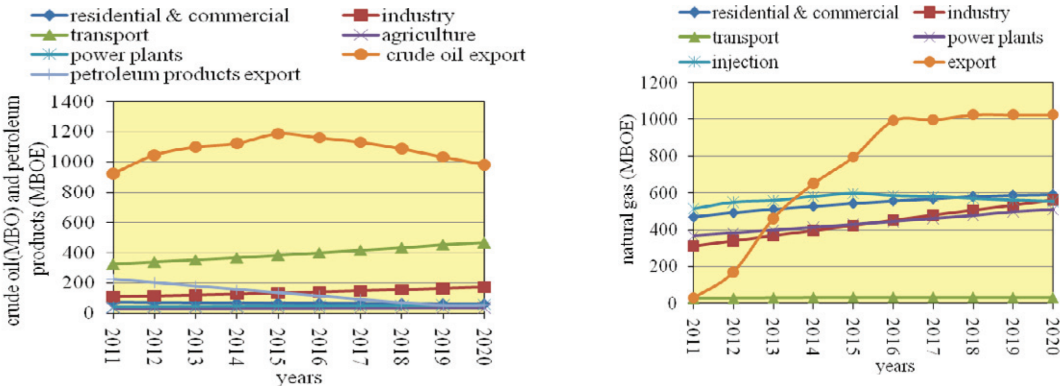

Fig. 2. (a) Crude oil and petroleum products optimal allocation from 2011 to 2020, (b) Natural gas optimal allocation from 2011 to 2020

4. Conclusions

In this paper an attempt had been made to develope a fuzzy multi-objective linear programming model for energy resources allocation in Iran considering political, economic and environmental objectives. Crude oil, petroleum products and natural gas had been allocated to various sectors consis of residential and commercial, transport, industry and agriculture sectors, power plants, injection in to the oil reservoirs and export from 2011 to 2020. The model gives decision-makers a tool to use in making strategic decisions on matters related to energy resources allocation in Iran.

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